
Comprehensive Report to Congress Clean Coal Technology Program

Commercial Demonstration of the NOXSO SO₂/NO_x Removal Flue Gas Cleanup System

**A Project Proposed By:
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1.0 EXECUTIVE SUMMARY

In September 1988, Congress provided \$575 million to conduct cost-shared Clean Coal Technology (CCT) projects to demonstrate technologies that are capable of retrofitting or repowering existing facilities. To that end, a Program Opportunity Notice (PON) was issued by the Department of Energy (DOE) in May 1989, soliciting proposals to demonstrate innovative energy efficient technologies that were capable of being commercialized in the 1990s, and were capable of (1) achieving significant reductions in the emissions of sulfur dioxide and/or the oxides of nitrogen from existing facilities to minimize environmental impacts such as transboundary and interstate pollution and/or (2) providing for future energy needs in an environmentally acceptable manner.

In response to the PON, 48 proposals were received in August 1989. After evaluation, 13 projects were selected in December 1989 as best furthering the goals and objectives of the PON. The projects were located in 10 different states and represented a variety of technologies.

One of the thirteen projects selected for funding is a project proposed by MK-Ferguson entitled "Commercial Demonstration of the NOXSO SO₂/NO_x Removal Flue Gas Cleanup System." This project will demonstrate the simultaneous removal of SO₂ and NO_x from flue gas by a regenerable sorbent. It will also demonstrate the ability of the NOXSO process to destroy the evolved NO_x and to recover elemental sulfur from the SO₂ in the flue gas.

In this project, the flue gas leaving the electrostatic precipitator (ESP) will be cooled by in-duct humidification and then routed to the fluid bed adsorbers, where SO₂ and NO_x will be adsorbed by the sorbent. The cleaned flue gas is then routed to the existing stack.

The sorbent is continuously regenerated in a series of steps, each of which is carried out in a separate vessel. These are:

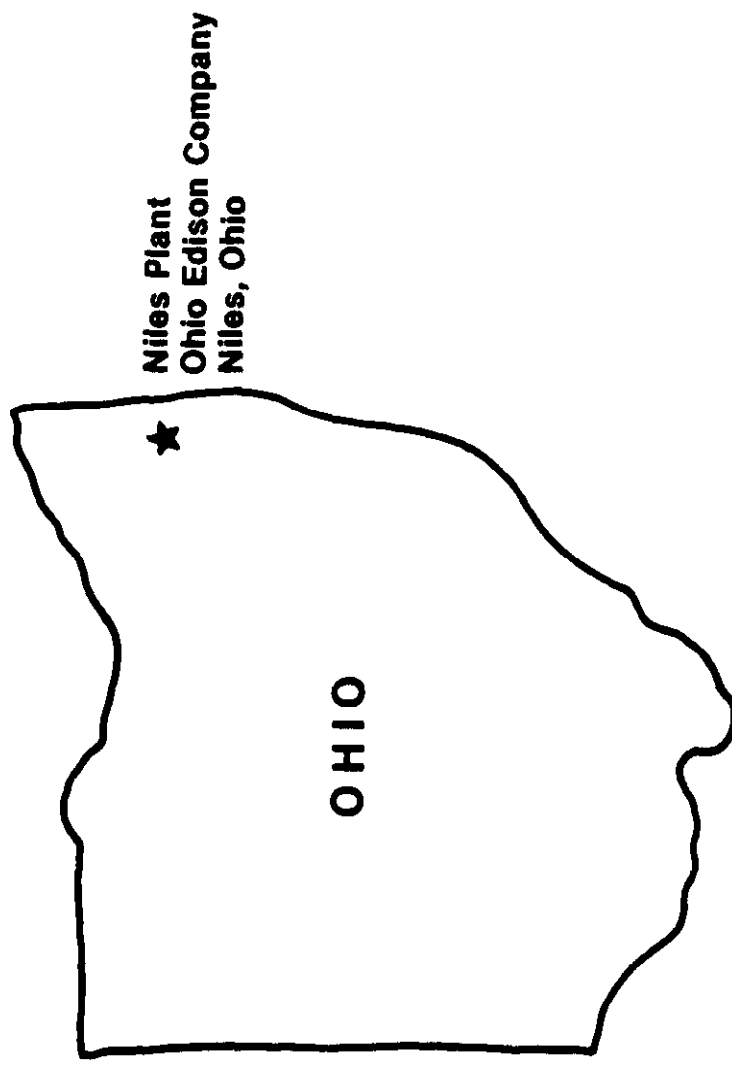
- o Heating, which releases the NO_x and heats the sorbent to the correct temperature for subsequent steps.
- o Treatment with a reducing gas (e.g., natural gas), which releases some of the adsorbed sulfur as SO₂ and H₂S.

- o Treatment with steam, which releases the balance of the sulfur as H_2S .
- o Cooling, which reduces the sorbent temperature to the proper temperature for return to the adsorber.

The NO_x liberated by heating is returned with the combustion air to the boiler. Since the boiler operates at near-equilibrium with respect to NO_x , recycling NO_x to the boiler creates a new equilibrium that does not greatly increase the NO_x concentration in the flue gas. The H_2S and SO_2 are sent to a Claus plant where they react in the presence of a catalyst to form elemental sulfur--a marketable by-product. The NOXSO process removes over 90% of the SO_2 and up to 70% of the NO_x from the incoming flue gas while generating no significant quantities of solid or liquid wastes. The removal rates of SO_2 and NO_x result in a combined reduction of over 90% for these acid rain precursors.

The project will be conducted at Ohio Edison's Niles Plant Unit 1, a 108 net megawatt electric (MWe) pulverized coal-fired cyclone boiler, located near Niles, in Trumbull County, Ohio. The location is shown in Figure 1. This project scale will demonstrate, if successful, the commercial applicability of the NOXSO process. Larger boilers will use multiple units of the module sizes to be demonstrated in this project. During the demonstration, the boiler will burn high-sulfur Ohio coals.

The total project cost is \$66,249,696. The DOE share will be \$33,124,848. MK-Ferguson, the Participant, along with NOXSO Corporation and WR Grace & Co.-CONN will contribute a total of \$22,806,498. Other co-funders are the Ohio Coal Development Office, Ohio Edison, the Gas Research Institute, the Electric Power Research Institute, and East Ohio Gas. The project is scheduled to last 70 months overall with the operational phase lasting 29 months.



**FIGURE 1. MK-FERGUSON NOXSO DEMONSTRATION
PROJECT LOCATION.**

2.0 INTRODUCTION AND BACKGROUND

2.1 Requirement for a Report to Congress

On September 27, 1988, Congress made available funds for the third clean coal demonstration program (CCT-III) in Public Law 100-446, "An Act Making Appropriations for the Department of the Interior and Related Agencies for the Fiscal Year Ending September 30, 1989, and for Other Purposes" (the "Act"). Among other things, this Act appropriates funds for the design, construction, and operation of cost-shared, clean coal projects to demonstrate the feasibility of future commercial applications of such "... technologies capable of retrofitting or repowering existing facilities" On June 30, 1989, Public Law 101-45 was signed into law, requiring that CCT-III projects be selected no later than January 1, 1990.

Public Law 100-446 appropriates a total of \$575 million for executing CCT-III. Of this total, \$6.906 million are required to be reprogrammed for the Small Business and Innovative Research Program (SBIR) and \$22.548 million are designated for Program Direction Funds for costs incurred by DOE in implementing the CCT-III program. The remaining, \$545.546 million was available for award under the PON.

The purpose of this Comprehensive Report is to comply with Public Law 100-446, which directs the Department to prepare a full and comprehensive report to Congress on each project selected for award under the CCT-III Program.

2.2 Evaluation and Selection Process

DOE issued a draft PON for public comment on March 15, 1989, receiving a total of 26 responses from the public. The final PON was issued on May 1, 1989, and took into consideration the public comments on the draft PON. Notification of its availability was published by DOE in the Federal Register and the Commerce Business Daily on March 8, 1989. DOE received 48 proposals in response to the CCT-III solicitation by the deadline, August 29, 1989.

2.2.1 PON Objective

As stated in PON Section 1.2, the objective of the CCT-III solicitation was to obtain "proposals to conduct cost shared Clean Coal Technology projects to demonstrate innovative, energy efficient technologies that are capable of being commercialized in the 1990s. These technologies must be capable of (1) achieving significant reductions in the emissions of sulfur dioxide and/or the oxides of nitrogen from existing facilities to minimize environmental impacts such as transboundary and interstate pollution and/or (2) providing for future energy needs in an environmentally acceptable manner."

2.2.2 Qualification Review

The PON established seven Qualification Criteria and provided that, "In order to be considered in the Preliminary Evaluation Phase, a proposal must successfully pass Qualification." The Qualification Criteria were as follows:

- (a) The proposed demonstration project or facility must be located in the United States.
- (b) The proposed demonstration project must be designed for and operated with coal(s) from mines located in the United States.
- (c) The proposer must agree to provide a cost share of at least 50 percent of total allowable project cost, with at least 50 percent in each of the three project phases.
- (d) The proposer must have access to, and use of, the proposed site and any proposed alternate site(s) for the duration of the project.
- (e) The proposed project team must be identified and firmly committed to fulfilling its proposed role in the project.
- (f) The proposer agrees that, if selected, it will submit a "Repayment Plan" consistent with PON Section 7.4.
- (g) The proposal must be signed by a responsible official of the proposing organization authorized to contractually bind the organization to the performance of the Cooperative Agreement in its entirety.

2.2.3 Preliminary Evaluation

The PON provided that a Preliminary Evaluation would be performed on all proposals that successfully passed the Qualification Review. In order to be considered in the Comprehensive Evaluation phase, a proposal must be consistent with the stated objective of the PON, and must contain sufficient business and management, technical, cost, and other information to permit the Comprehensive Evaluation described in the solicitation to be performed.

2.2.4 Comprehensive Evaluation

The Technical Evaluation Criteria were divided into two major categories: (1) the Demonstration Project Factors were used to assess the technical feasibility and likelihood of success of the project, and (2) the Commercialization Factors were used to assess the potential of the proposed technology to reduce emissions from existing facilities, as well as to meet future energy needs through the environmentally acceptable use of coal, and the cost effectiveness of the proposed technology in comparison to existing technologies.

The Business and Management criteria required a Funding Plan and an indication of Financial Commitment. These were used to determine the business performance potential and commitment of the proposer.

The PON provided that the Cost Estimate would be evaluated to determine the reasonableness of the proposed cost. Proposers were advised that this determination "will be of minimal importance to the selection," and that a detailed cost estimate would be requested after selection. Proposers were cautioned that if the total project cost estimated after selection is greater than the amount specified in the proposal, DOE would be under no obligation to provide more funding than had been requested in the proposer's Cost Sharing Plan.

2.2.5 Program Policy Factors

The PON advised proposers that the following program policy factors could be used by the Source Selection Official to select a range of projects that would best serve program objectives:

- (a) The desirability of selecting projects that collectively represent a diversity of methods, technical approaches, and applications.

- (b) The desirability of selecting projects in this solicitation that contribute to near term reductions in transboundary transport of pollutants by producing an aggregate net reduction in emissions of sulfur dioxide and/or the oxides of nitrogen.
- (c) The desirability of selecting projects that collectively utilize a broad range of U.S. coals and are in locations which represent a diversity of EHSS, regulatory, and climatic conditions.
- (d) The desirability of selecting projects in this solicitation that achieve a balance between (1) reducing emissions and transboundary pollution and (2) providing for future energy needs by the environmentally acceptable use of coal or coal-based fuels.

The word "collectively" as used in the foregoing program policy factors, was defined to include projects selected in this solicitation and prior clean coal solicitations, as well as other ongoing demonstrations in the United States.

2.2.6 Other Considerations

The PON provided that in making selections, DOE would consider giving preference to projects located in states for which the rate-making bodies of those states treat the Clean Coal Technologies the same as pollution control projects or technologies. This consideration could be used as a tie breaker if, after application of the evaluation criteria and the program policy factors, two projects receive identical evaluation scores and remain essentially equal in value. This consideration would not be applied if, in doing so, the regional geographic distribution of the projects selected would be altered significantly.

2.2.7 National Environmental Policy Act (NEPA) Compliance

As part of the evaluation and selection process, the Clean Coal Technology Program developed a procedure for compliance with the National Environmental Policy Act of 1969 (NEPA), the Council on Environmental Quality regulations for implementing NEPA (40 CFR 1500-1508) and the DOE guidelines for compliance with NEPA (52 FR 47662, December 15, 1987).

This procedure included the publication and consideration of a publicly available Final Programmatic Environmental Impact Statement (DOE/EIS-0146) issued in November 1989, and the preparation of confidential preselection project-specific

environmental reviews for internal DOE use. DOE also prepares publicly available site-specific documents for each selected demonstration project as appropriate under NEPA.

2.2.8 Selection

After considering the evaluation criteria, the program policy factors, and the NEPA strategy as stated in the PON, the Source Selection Official selected 13 projects as best furthering the objectives of the CCT-III PON.

Secretary of Energy, Admiral James D. Watkins, U.S. Navy (Retired), announced the selection of 13 projects on December 21, 1989. In his press briefing, the Secretary stated he had recently signed a DOE directive setting a 12 month deadline for the negotiation and approval of the 13 cooperative agreements to be awarded under the CCT-III solicitation.

3.0 TECHNICAL FEATURES

3.1 Project Description

The MK-Ferguson NOXSO demonstration project will, if successful, show that the NOXSO process is a technically and economically viable technology for the removal of SO₂ and NO_x from the flue gas of coal-fired power plants. It will also demonstrate that the NO_x can be removed from the sorbent and destroyed (converted to N₂) in the boiler, and that elemental sulfur can be recovered from the H₂S and SO₂ evolved during sorbent regeneration. The NOXSO process will be demonstrated at the commercial scale in an operating utility plant. Once proven, the process can be adapted to any boiler size, either by scaleup or by the use of multiple modules.

The NOXSO process, according to the Participant, offers several advantages over conventional flue gas cleanup processes. It simultaneously removes both SO₂ and NO_x while generating no significant quantities of solid or liquid waste. The only by-product is elemental sulfur, which is readily marketable. In addition, the Participant estimates that capital and operating costs are lower than those for conventional flue gas desulfurization (FGD) combined with selective catalytic reduction (SCR) for NO_x removal.

This demonstration project will be conducted at Ohio Edison's Niles Plant Boiler Unit 1, located in Trumbull County, Ohio. This unit is a 108 Mwe, pulverized coal-fired cyclone boiler. During the project, the host boiler will burn high-sulfur bituminous coal mined locally. This coal will be mined from the Lower Kittanning and Upper Freeport seams. The host boiler is equipped with cyclone burners which tend to produce high levels of NO_x . The 108 Mwe size of the demonstration plant will provide realistic cost data for commercial installations. A modest scaleup will be necessary for the largest size boilers in NOXSO's anticipated market (i.e., 100-500 MWe). Since the host boiler is at the lower end of this size range, the project will fully demonstrate the technical and economic advantages of the NOXSO process in a full-scale commercial installation while holding down project costs.

The goal of this program is to demonstrate the technical and economic feasibility of the NOXSO process. The project is designed to demonstrate a total reduction of 90% of the acid rain precursors, SO_2 and NO_x . It will also demonstrate the production of commercial grade elemental sulfur. If successful, these performance goals will be met with lower capital and operating costs than possible with other SO_2/NO_x removal systems.

3.1.1 Project Summary

Project Title:	Commercial Demonstration of the NOXSO SO ₂ /NO _x Removal Flue Gas Cleanup System
Proposer:	MK-Ferguson
Project Location:	Niles, Ohio (Ohio Edison's Niles Plant) Trumbull County
Technology:	Post-Combustion Flue Gas Cleanup
Application:	Coal-Fired Industrial and Utility Boilers, New and Retrofit
Type of Coal Used:	High-Sulfur Southeastern Ohio Coal
Product:	Environmental Control Technology
Project Size:	108 MWe
Project Start Date:	February 1991
Project End Date:	November 1996

3.1.2 Project Sponsorship and Cost

Project Sponsor: MK-Ferguson

Co-Funders
NOXSO Corporation
W.R. Grace & Company
Ohio Edison Company
Ohio Coal Development Office
Gas Research Institute
Electric Power Research Institute
East Ohio Gas

Proposed Project Cost: \$66,249,696

Proposed Cost

Distribution:	Participant	DOE
	<u>Share (%)</u>	<u>Share (%)</u>
	50.0	50.0

3.2 NOXSO Process

3.2.1 Overview of Process Development

Since the company's inception in 1979, NOXSO Corporation's sole business activity has been the development of the NOXSO flue gas treatment process. The NOXSO process development program has been a series of projects in which operating and performance data have been obtained from test units of ever increasing size. The proposed demonstration project is the last step in the NOXSO development program. MK-Ferguson and its team plan to market the NOXSO process to industry using the cost and performance data obtained in this demonstration project.

The initial tests of the NOXSO process were carried out at TVA's Shawnee Steam Plant in Paducah, KY between August 1982 and March 1985. The first tests used a fixed-bed bench-scale unit that treated 0.35 standard cubic feet per minute (SCFM) of flue gas. Later tests, carried out at the Shawnee Steam Plant, utilized a pre-pilot-scale fluidized bed adsorber and treated 50 SCFM of flue gas. These tests produced process performance data and data on process chemistry and kinetics using actual flue gas. Prior tests used synthetic flue gas. The 50 SCFM unit also tested the chemical activity of the sorbent during multiple

adsorption-desorption cycles, established the fundamental relationship between sorbent sodium content and attrition strength, demonstrated the feasibility of using different reducing gases for sorbent regeneration, and provided the initial design and economic data.

Following these tests, additional work was done at the Pittsburgh Energy Technology Center (PETC). The first tests at PETC were carried out on a 100 SCFM Life Cycle Test Unit (LCTU). This unit demonstrated, for the first time, the integrated NOXSO process. It also established required flue gas residence times, demonstrated the sorbent's chemical activity and attrition strength through multiple adsorption/desorption cycles, provided 1000 hours of parametric tests, and demonstrated the use of natural gas as a reducing gas.

In 1985 and 1986, NOXSO Corporation carried out additional tests at PETC. These tests were at the 1200 SCFM level. These tests provided additional data at a larger scale, which is necessary for the continued scaleup of the process. These tests also showed the ability of the NOXSO adsorber to operate with a high ash loading and provided data on NO_x recycle.

With DOE funding, MK-Ferguson and its team are currently involved in a project to conduct proof-of-concept (POC) tests of the NOXSO process at Ohio Edison's Toronto, Ohio Station. This unit will treat a slip stream of approximately 12,000 SCFM of flue gas produced by burning high sulfur coal. This size is roughly equivalent to a 5 MWe unit. It will consist of a fully integrated process module and will provide the design and operational data required for the 108 MWe demonstration at the Niles Plant. These proof-of-concept tests are scheduled for completion in October 1991.

This CCT demonstration, at the 108 MWe scale, is the final step necessary to fully demonstrate the commercial applicability of the NOXSO process.

3.2.2 Process Description

The flue gas leaving the boiler passes first through the air heater, and particulate removal device before being diverted to the NOXSO process. While this configuration will be used at the Niles Plant, the sorbent design allows the NOXSO process to be placed upstream of the particulate removal device. A simplified process flow diagram is shown in Figure 2.

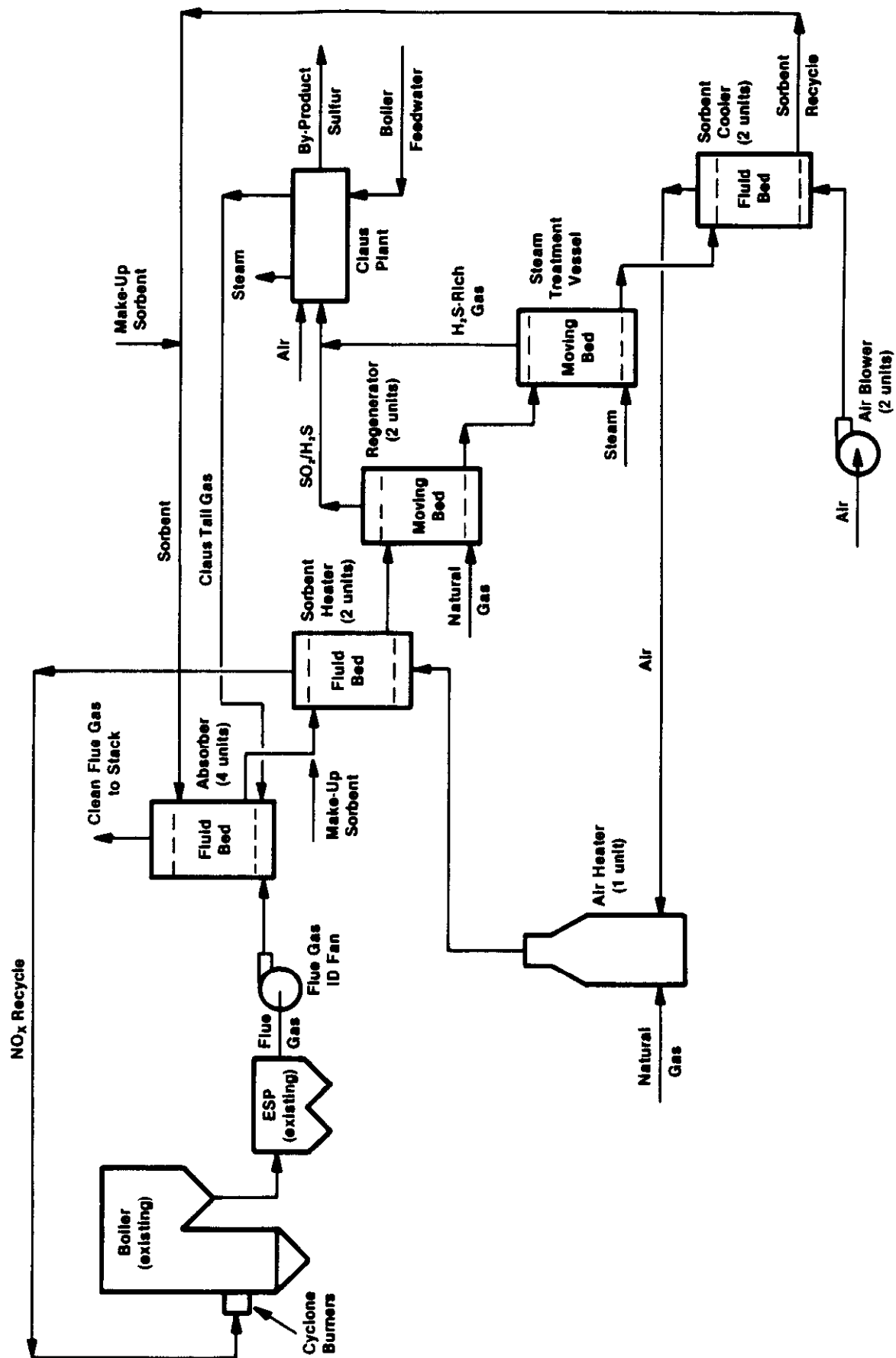


FIGURE 2. NOXSO PROCESS FLOW DIAGRAM.

The flue gas leaving the particulate removal device goes to a new induced draft fan that provides the pressure required to overcome the pressure drop in the adsorbers and adsorber cyclones. The flue gas is then cooled by adiabatic humidification in the duct before it passes through one of the four parallel fluid-bed adsorbers. The sorbent is a high surface area alumina (Al_2O_3) that has been impregnated with sodium carbonate. The flue gas is used to fluidize the dry, solid sorbent and as the flue gas passes upward through the fluid bed, the SO_2 and NO_x are adsorbed onto the sorbent. The flue gas then passes through the adsorber cyclone to remove entrained sorbent particles and the clean flue gas is then discharged through the existing stack.

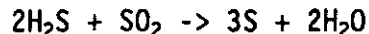
Sorbent is continually withdrawn from the adsorbers and passed to two parallel sorbent heaters. These heaters are three-stage overflowing fluid bed systems. Fluidizing gas and heat are provided by the discharge stream from an air heater. The air heater burns natural gas and mixes the combustion products with air that has been partially heated in the sorbent coolers, which will be described later. In the sorbent heaters, the sorbent is heated to about 1200 °F, the temperature required for regeneration. As a result of this heating, the NO_x is desorbed from the sorbent along with a very small amount of SO_2 . This heating gas stream transports the NO_x and SO_2 to the boiler. Ultimately, the SO_2 will be re-adsorbed. At normal operation, the boiler's cyclone burners operate at near-equilibrium with respect to NO_x formation. Therefore, the recycled NO_x will either dissociate into oxygen and nitrogen or it will suppress the formation of NO_x at the burners so that the NO_x level establishes a new equilibrium.

The heated sorbent is transferred from the sorbent heaters to one of two parallel moving-bed regenerators. In these vessels, the sorbent is contacted with a reducing gas. For this project, natural gas, which is predominantly methane (CH_4), is used; but other combustible gases are suitable. These include carbon monoxide (CO), hydrogen (H_2) or mixtures of CH_4 , CO , and H_2 . In the regenerator, the sulfur compounds on the sorbent are reduced to SO_2 and H_2S (primarily SO_2) and are evolved into the reducing gas stream. Small quantities of carbonyl sulfide (COS) and elemental sulfur are also formed and evolved into the reducing gas stream. During regeneration with CH_4 , about 65% of the adsorbed sulfur is reduced to sodium sulfide (Na_2S) which remains on the sorbent. The off-gas from regeneration is sent to a sulfur recovery process.

The sorbent leaving the regenerators is sent to one of two parallel, moving-bed steam treatment vessels. In the steam treatment vessel, the sorbent is contacted by steam which hydrolyzes the Na_2S to form Na_2O and H_2S . This produces a concentrated H_2S stream that is mixed with the off-gas from the regenerators and sent to a sulfur recovery unit.

The sorbent leaving the steam treatment vessels is next sent to two parallel, fluid-bed sorbent coolers. In the sorbent coolers, the sorbent is fluidized and cooled by a stream of air provided by two sorbent cooler blowers. The cool, regenerated sorbent is transferred from the sorbent cooler to the adsorbers to begin a new cycle. The cooling air from the sorbent coolers flows to the air heater where it is used as heated combustion air. This gas stream flows to the boiler after passing through the sorbent heater.

The H_2S from the steam treatment vessels is combined with the SO_2 -bearing stream from the regenerator and sent to a sulfur recovery unit. These streams could also be used to produce sulfuric acid, but elemental sulfur will be produced at the Niles Plant. It is recovered via the following reaction:



Since there is a slight excess of H_2S (compared with SO_2) when CH_4 is used as the reducing agent, some H_2S needs to be oxidized. This is accomplished in a catalytic bed. In this process, some air is mixed with the feed stream and a portion of the H_2S is catalytically oxidized to SO_2 . In addition, some of the H_2S and SO_2 react to form elemental sulfur in this process. Due to the temperatures involved, the sulfur product leaving the catalytic reactor is a vapor. The exit gas is cooled and sulfur is condensed in a waste heat boiler that generates low pressure steam. The gas is then reheated and sent to a conventional Claus reactor where most of the remaining H_2S and SO_2 react. The gas is again cooled to condense sulfur and then sent to the adsorbers where residual sulfur compounds are removed. It should be noted that the small quantity of COS contained in the sulfur recovery feed gas is hydrolyzed to form H_2S and CO_2 . This H_2S is then reacted in the same manner as the H_2S contained in the feed gas.

The net effect of the NOXSO process is that 90% of the acid rain precursors are removed from the flue gas without generating the large quantities of solid waste typical of the "throw-away" processes that use lime or limestone and produce a waste product. The removal rate for acid rain precursors is based on a 97%

removal rate for SO_2 and a 70% removal rate for NO_x which results in an overall removal rate of 90% by weight of the combined acid rain precursors.

3.2.3 Application of Process in Proposed Project

The Niles Plant Unit No. 1 is a nominal 108 MWe coal-fired cyclone boiler that is equipped with an ESP. Implementation of the NOXSO process will require installation of an off-take duct between the stack and the ESP. This duct must include dampers to direct the flue gas flow either to the NOXSO process or to the stack. The new duct will lead to the ID fans and then to the adsorbers and will include spray nozzles for cooling the flue gas. A new duct will also be installed from the adsorbers back to the existing duct. Tie-in of the new duct and the installation of the NO_x recycle line to the boiler are the only parts of the project that will require shutdown of the boiler since installation of the adsorbers, sorbent heaters, regenerators, steam treatment vessels, sorbent coolers, air heater fans, blowers, and the sulfur recovery unit can be done while Unit No. 1 is in operation.

The specific objectives of the demonstration at the Niles Plant are to: (1) demonstrate the feasibility of the integrated NOXSO process as applied to a power plant fired with high-sulfur coal; (2) achieve up to 90% removal of SO_2 and 70% of the NO_x at various plant loads; (3) demonstrate the commercial quality of the sulfur product; (4) determine the attrition rate and life of the sorbent; (5) demonstrate the ability to control NO_x emissions by recycling NO_x to the boiler; and (6) confirm capital, operating, and maintenance costs.

3.3 General Features of the Project

3.3.1 Evaluation of Developmental Risk

As with any new or developing technology, there is an element of developmental risk in its continued development. However, as previously described, the NOXSO process has undergone about ten years of development and has been tested at several scales, each progressively larger. These tests have covered all process steps that are part of the NOXSO process and all aspects of the process including NO_x removal and sorbent attrition. In addition, an integrated NOXSO process at the POC scale (12,000 SCFM) is being installed at the Toronto Station of Ohio Edison. Data from this POC unit will be available in time to finalize the design

of the commercial scale demonstration at the Niles Plant. In conjunction with this process development work, W.R. Grace & Company has been actively working on sorbent improvement.

After reviewing the results of the development work, an acceptable risk factor has been assigned to this project. However, some technical risks do exist. Since the process has not been run at a large integrated facility, several aspects of the process have not been tested at the scale used in this project. These include NO_x recycle, sorbent life/attrition, gas distribution in both the parallel ducts and the fluid beds, and sulfur quality. As described earlier, much prior testing, at a smaller scale, has been done and fluid beds larger than those required for this demonstration project are commonly used in the chemical and petroleum industries. This relevant experience indicates that these potential problems are manageable.

In addition to the technical risks, there are certain related economic risks associated with the NOXSO process. If sorbent attrition greatly exceeds expectations, operating costs will increase due to sorbent replacement costs and additional particulate removal equipment will be required on the flue gas leaving the adsorbers.

3.3.1.1 Similarity of the Project to Other Demonstration/ Commercial Efforts

The majority of simultaneous SO_2/NO_x flue gas treatment systems are wet adsorption processes developed and operated in Japan. The NOXSO process, developed in the U.S., is one of the few dry SO_2/NO_x control systems developed beyond laboratory scale. Some of the other processes of this type are the copper oxide, the electron beam, and the SNRB processes.

The copper oxide process was developed and is marketed by Shell/UOP. The process uses an acceptor/catalyst (copper oxide) in fixed beds to absorb SO_2 and NO_x . The NO_x is ultimately destroyed via selective catalytic reduction in which the NO_x reacts with ammonia in the presence of a catalyst to produce nitrogen and water vapor. The SO_2 is ultimately converted to either sulfuric acid or sulfur, both of which are saleable by-products. The copper oxide process, which is less effective at removing NO_x than the NOXSO process, is in commercial use in six NO_x removal applications on oil- or gas-fired units and is undergoing demonstration on a coal-fired fluid-bed combustor.

The electron beam (E-beam) process is another simultaneous SO_2/NO_x flue gas treatment system being developed in the U.S. In this process, the flue gas is irradiated with a concentrated beam of high energy electrons. This irradiation excites the gas molecules and produces a supply of radicals, ions, and free atoms in the flue gas stream. Those excited species containing oxygen atoms will oxidize SO_2 and NO_x in the flue gas to produce higher oxides. These resultant acidic compounds are more readily extracted from the flue gas than are SO_2 and NO_x . The extraction is accomplished with a lime spray dryer. The spent sorbent is collected, along with fly ash, in conventional particulate removal equipment and sent to a disposal facility. In addition to producing significant quantities of solid waste, the E-beam process has a higher energy requirement than most competing processes.

The WSA-SNOX process simultaneously removes SO_2 and NO_x and is being demonstrated as part of the second round of the CCT program. In the WSA-SNOX process, flue gas containing NO_x and SO_2 formed during coal combustion is first processed through particulate removal equipment and heated to reaction temperature. A small quantity of ammonia is then injected into the flue gas and the mixture passes through the NO_x reactor where nitrogen oxides are catalytically converted to nitrogen and water vapor. The flue gas leaving the NO_x reactor is further heated and processed through an SO_2 reactor where the SO_2 is converted to sulfur trioxide (SO_3). The flue gas leaving the SO_2 reactor is first cooled by the flue gas coming from the particulate removal unit and then passed through a condensing tower where marketable, high-concentration sulfuric acid is formed. Unconverted ammonia, carbon monoxide and hydrocarbons are oxidized in the SO_2 reactor and essentially all remaining particulates are retained in the reactor's catalyst bed.

The SOX-NOX-ROX Box (SNRB) process will demonstrate simultaneous removal of SO_2 and NO_x in a CCT-II project. In the SNRB process, sulfur dioxide is removed by injecting a sorbent, either sodium- or calcium-based, into the flue gas between the upper part of the boiler combustion zone and the economizer outlet. The sorbent reacts with the SO_2 to form a solid particulate, which is removed in the baghouse. Preliminary evaluations, based on reagent costs and solid waste disposal costs, indicate that calcium-based sorbents would be preferred reagents for applications in Eastern regions of the United States, while sodium-based sorbent would be preferred for Western applications. Flyash is also removed by the baghouse.

The NO_x reduction is accomplished by selective catalytic reduction (SCR) using ammonia injected upstream of the baghouse. Some NO_x removal occurs in the presence of injected sorbent, while the balance is removed in the presence of the SCR catalyst in the baghouse. The catalyst converts ammonia and NO_x to nitrogen and water vapor in the temperature range at which the baghouse operates -600 to 800 degrees Fahrenheit (°F).

Numerous other technologies exist for SO₂ and NO_x removal. However, these systems typically use two unrelated but compatible technologies for SO₂ and NO_x control. Typically, NO_x control is accomplished by low-NO_x burners, reburning, or reduction with ammonia or urea. The reduction reactions are usually enhanced by high temperature (thermal de-NO_x) or by using a catalyst (SCR). These NO_x-reduction technologies are typically tied to a sorbent-based technology such as spray drying, duct or furnace injection, or wet flue gas desulfurization processes, all of which produce large quantities of sludge or dry waste.

3.3.1.2 Technical Feasibility

The NOXSO process has been under development since 1979. The process has been tested up to the 1,200 SCFM level, and prior to completion for the design of the Niles demonstration plant, the process will be tested at the 12,000 SCFM (about 5 MWe) level at Ohio Edison's Toronto Station. The tests already completed have shown the technical feasibility of the adsorption, heating, regeneration, steam treatment, cooling, and NO_x recycle steps. The Toronto POC tests will test the integrated process with the exception of NO_x recycle and sulfur recovery. These tests will provide excellent design data for the demonstration plant. The sulfur recovery step has not been tested as part of a NOXSO facility. Claus-type sulfur recovery units utilize the standard, commercial technology for sulfur recovery and are located in many plants around the world. Units recovering thousands of tons of sulfur per day are presently in operation.

Evidence of the NOXSO process's feasibility is also provided by the level of interest in the NOXSO process. During the more than ten years of development, funds and/or services have been contributed by NOXSO Corporation, MK-Ferguson, the DOE, the TVA, W.R. Grace & Company, the Ohio Coal Development Office, the Electric Power Research Institute, Ohio Edison, and the Gas Research Institute.

The interest in the NOXSO process and the success of the NOXSO process in past tests indicate that the NOXSO process is technically feasible and that this demonstration should achieve its goal of 90% removal of acid rain precursors.

3.3.1.3 Resource Availability

Adequate resources are available for this project over the 61-month demonstration period. Co-funders have committed adequate funds, as discussed in Section 6.1, to cover the proposed project cost. They have also dedicated sufficient personnel to conduct the demonstration program. The skilled and unskilled labor required for construction and operation of the project will be readily obtainable, since the Niles Plant is located in an industrial region that has a large population of qualified people.

Sufficient space is available at the Niles Plant for erection of the demonstration equipment. Neither the quantity nor the quality of the coal now being burned by the Niles Plant boiler No. 1 will change during the demonstration period, and the project will use the existing coal handling system.

The resources required for the demonstration include sorbent, cooling water, the sulfur recovery catalysts, electrical power, and natural gas. Sorbent and the catalysts can be readily supplied in the quantities required. Electrical power and cooling water can be supplied in the required quantities by the existing plant systems. Natural gas is currently at the plant boundary and a tie-in line is being installed as part of another project.

3.3.2 Relationship Between Project Size and Projected Scale of Commercial Facility

The demonstration will be conducted on a 108 MWe utility boiler, using the entire flue gas stream. There are some commercial fluid bed systems used in other applications that are up to 40 feet in diameter (compared to 25 feet for this project's adsorbers) so some additional scaleup of the NOXSO adsorbers is possible without significant risk. In addition, the NOXSO process is modular in design so that larger commercial plants could be designed by adding more units. The sulfur recovery unit is basically a separable part of the system which has been commercially available on a much larger scale for some time.

The risk of scaleup is considered to be minimal and the demonstration is expected to prove the applicability of the NOXSO process for retrofit on pre-NSPS boilers or for use on new boilers without further demonstration.

3.3.3 Role of the Project in Achieving Commercial Feasibility of the Technology

This project will demonstrate, at the utility scale, a new flue gas cleanup technology for removal of suspected acid rain precursors. This technology can enhance the use of medium- and high-sulfur coals under conditions requiring compliance with environmental regulations. The commercialization of the NOXSO technology requires a comprehensive data base for coal-fired applications that demonstrates the emission control, performance, reliability, and cost effectiveness of the process. The suitability of the NOXSO process for utility boilers will be fully established when it is demonstrated that NO_x and SO₂ can be removed from flue gas to required compliance levels at costs that are favorable when compared with the costs of current flue gas cleanup technologies.

3.3.3.1 Applicability of the Data to be Generated

The demonstration unit proposed for Ohio Edison's Niles Plant will complete the series of development steps designed to commercialize the NOXSO Flue Gas Treatment Process. Research has progressed from the laboratory-scale (0.35 SCFM) to the POC pilot-scale (12,000 SCFM) with intermediate tests providing engineering and scaleup data.

A primary goal of this project will be to show that the NOXSO process can remove 90% of the combined SO₂ and NO_x emissions from a commercial-scale facility. In particular, it will be important to demonstrate that the prescribed removal efficiencies are attainable over an anticipated range of boiler loads and conditions.

An automated data collection system will be used. On-line analyses of the inlet and outlet flue gas from the adsorber will be continuously performed to determine SO₂ and NO_x removal efficiencies. Particulate sampling will be performed at the exit streams from the adsorber cyclones and the exit streams from the sorbent heaters to provide data on the particle size distribution of attrited sorbent.

In addition to the continuous gas monitors on the flue gas entering and exiting the adsorber, all process streams will be monitored to allow complete material balance closure. To this end, sorbent samples will also be taken periodically and sent to a laboratory for analysis.

Economic data obtained from the full-scale demonstration will be used to verify the capital and operating costs of the NOXSO process. The various tests will identify the optimum operating conditions for the NOXSO process. Sorbent inventories in each vessel will also be determined to allow more accurate determination of the cost for the initial sorbent charge. Capital costs for a commercial unit can then be determined.

Operating costs will be determined primarily during Phase III operations during this NOXSO demonstration project. The duration test will be performed at optimum system conditions as identified during the parametric tests. The operating costs of primary importance include sorbent make-up feedrate, electricity costs, natural gas consumption, steam consumption, and sulfur production rate.

Thus, if successful, this project will demonstrate the SO₂ and NO_x removal capabilities of the NOXSO process, and will provide all necessary technical and economic data for the commercialization of the NOXSO process.

3.3.3.2 Identification of Features that Increase Potential for Commercialization

The NOXSO process, once commercially proven, will provide an economical and technically acceptable system for the simultaneous control of NO_x and SO₂. The competitive capital and operating costs, high NO_x and SO₂ removal rates, and the production of a marketable commodity (elemental sulfur), make the NOXSO process attractive for new and retrofit applications.

A NOXSO process installation would consist largely of proven, commercially available unit operations and equipment such as fluid- and moving-bed systems, blowers, Claus reactors, etc. Although fluid- and moving-bed systems have not been used specifically in this application, they are common in other industries.

In summary, commercialization of the technology will be aided by:

- o High removal rates of NO_x and SO_2 .
- o Simultaneous removal of NO_x and SO_2 .
- o No stack gas reheat required to avoid condensation in the stack.
- o No sludge or spent sorbent produced that requires disposal.
- o Production of a marketable by-product (sulfur).
- o Demonstration of an effective process to treat flue gas produced from high-sulfur coal.

The success of this demonstration will establish that the NOXSO process is an effective, reliable, and cost competitive approach to the control of the two major pollutants associated with acid rain. Accordingly, this technology has the potential to penetrate the large pre-NSPS boiler and new coal-fired boiler market for all types of boilers to a significant extent.

3.3.3.3 Comparative Merits of Project and Projection of Future Commercial Economics and Market Acceptability

The NOXSO process, assuming successful demonstration of the technology, will provide the utility industry with a technically sound and cost competitive way to simultaneously remove NO_x and SO_2 from coal-derived flue gas.

The location and characteristics of the host site, in addition to the process's capabilities, are additional advantages to this project. The host boiler is a base-load, commercially-operating, cyclone-fired boiler that uses high-sulfur coal. Since cyclone burners normally produce higher NO_x levels than most other types of boilers, the NOXSO process will be tested on a flue gas stream high in both SO_2 and NO_x . The size (108 MWe) of the boiler is sufficiently large to be a full commercial-scale demonstration, but is still small enough to keep costs down for the demonstration. In addition, all labor and material required for the demonstration is available or can easily be made available and a local market exists for the sulfur by-product.

In addition to these site characteristics and process advantages, the NOXSO process is expected to be economically competitive. EPRI estimates show that the NOXSO process has capital costs that are 4% lower than conventional wet-FGD combined with SCR for NO_x control and that operating costs are 24% lower for the NOXSO process.

Due to the technical, environmental, and economic advantages of the NOXSO process, it is expected that the NOXSO process, once demonstrated, will be accepted as a viable alternative to the existing, commercially available processes. It is also expected that the NOXSO process will be competitive for both new and retrofit applications.

4.0 ENVIRONMENTAL CONSIDERATIONS

The NEPA compliance procedure, cited in Section 2.2, contains three major elements: a Programmatic Environmental Impact Statement (PEIS); a preselection, project-specific environmental review; and a post-selection, site-specific environmental review. DOE issued the final PEIS to the public in November 1989 (DOE/EIS-0146). In the PEIS, results derived from the Regional Emissions Database and Evaluation System (REDES) were used to estimate the environmental impacts expected to occur in 2010 if each technology were to reach full commercialization, capturing 100 percent of its applicable market. These impacts were compared to the no-action alternative, which assumed continued use of conventional coal technologies through 2010 with new plants using conventional flue gas desulfurization to meet New Source Performance Standards.

The preselection, project-specific environmental review focusing on environmental issues pertinent to decision-making was completed for internal DOE use. The review summarized the strengths and weaknesses of each proposal against the environmental evaluation criteria in the PON. It included, to the extent possible, a discussion of alternative sites and processes reasonably available to the offeror, practical mitigating measures, and a list of required permits. This analysis was provided for consideration of the Source Selection Official in the selection of proposals.

To complete the final element of the NEPA strategy, the Participant (MK-Ferguson) submitted to DOE the environmental information volume specified in the PON. This detailed site- and project-specific information formed the basis for the NEPA documents prepared by DOE. This document, prepared in compliance with the Council on Environmental Quality regulations for implementation of NEPA (40 CFR Parts 1500-1508) and DOE guidelines for NEPA compliance (52 FR 47662), must be approved before federal funds can be provided for any activity that would limit the choice of reasonable alternatives to the proposed action.

In addition to the NEPA requirements outlined above, the Participant must prepare and submit an Environmental Monitoring Plant (EMP) for the project. The purpose of the EMP is to ensure that sufficient technology, project, and site environmental data are collected to provide health, safety, and environmental information for use in subsequent commercial applications of the technology.

The expected performance characteristics and applicable market for the NOXSO technology are anticipated to be similar to those of the copper oxide process. The environmental impacts in 2010 which would result from full commercialization of the copper oxide process have been evaluated. The REDES model was used to compare copper oxide process technology impacts to the no-action alternative.

Projected environmental impacts from commercialization of the copper oxide process technology into national and regional areas in 2010 are given in Table 1. Negative percentages indicate decreases in emissions or wastes in 2010. These results should be regarded as approximations of actual impacts.

Table 1
Projected Environmental Impacts in 2010
(Percent Change in Emissions and Solid Wastes)

Region	Sulfur Dioxide	Nitrogen Oxides	Solid Wastes
National	-45	-33	-22
Northeast	-65	-45	-23
Southeast	-52	-40	-22
Northwest	-10	-10	- 3
Southwest	-15	-22	-24

Source: Programmatic Environmental Impact Statement (DOE/EIS-0146) November 1989.

As shown in Table 1, significant reductions of SO₂ and NO_x are projected to be achievable nationally due to the capability of the process to remove 90% of SO₂ and NO_x emissions from coal-fired boilers and the wide potential applicability of the process. The REDES model predicts greatest environmental impacts will be felt in the Northeast because of the large amount of coal-fired capacity there that can be retrofitted with the process. The least impact occurs in the Northwest because of the minimal use of coal there. The REDES model predicts

that solid waste would decrease as much as 22% nationally. The national quadrants used in this study are depicted in Figure 3.

5.0 PROJECT MANAGEMENT

5.1 Overview of Management Organization

MK-Ferguson, NOXSO Corporation, W.R. Grace & Co., and Ohio Edison will perform the work required of this demonstration project. The respective parties will make contributions to the conduct of the project performance related to their capabilities as generally set forth below:

- o MK-Ferguson will provide overall project management, detailed design, procurement, construction, construction management, and plant operation capabilities.
- o NOXSO will provide process technology, conceptual design, testing, and data collection and analysis capabilities.
- o W.R. Grace will provide the process sorbent material and technical expertise related to facility operation and sorbent test data analyses.
- o Ohio Edison will provide the host site and operating and maintenance expertise.

The project will be managed by MK-Ferguson's Program manager. He will be the principal contact with DOE for matters regarding the administration of the Cooperative Agreement. The DOE Contracting Officer is responsible for all contract matters and the DOE Contracting Officer's Technical Representative (COTR) is responsible for technical liaison and monitoring of the project.

The cofunding of the project will be provided by the U.S. Department of Energy, MK-Ferguson, NOXSO Corporation, W.R. Grace & Company, Ohio Edison, the Ohio Coal Development Office, the Gas Research Institute, East Ohio Gas, and the Electric Power Research Institute.

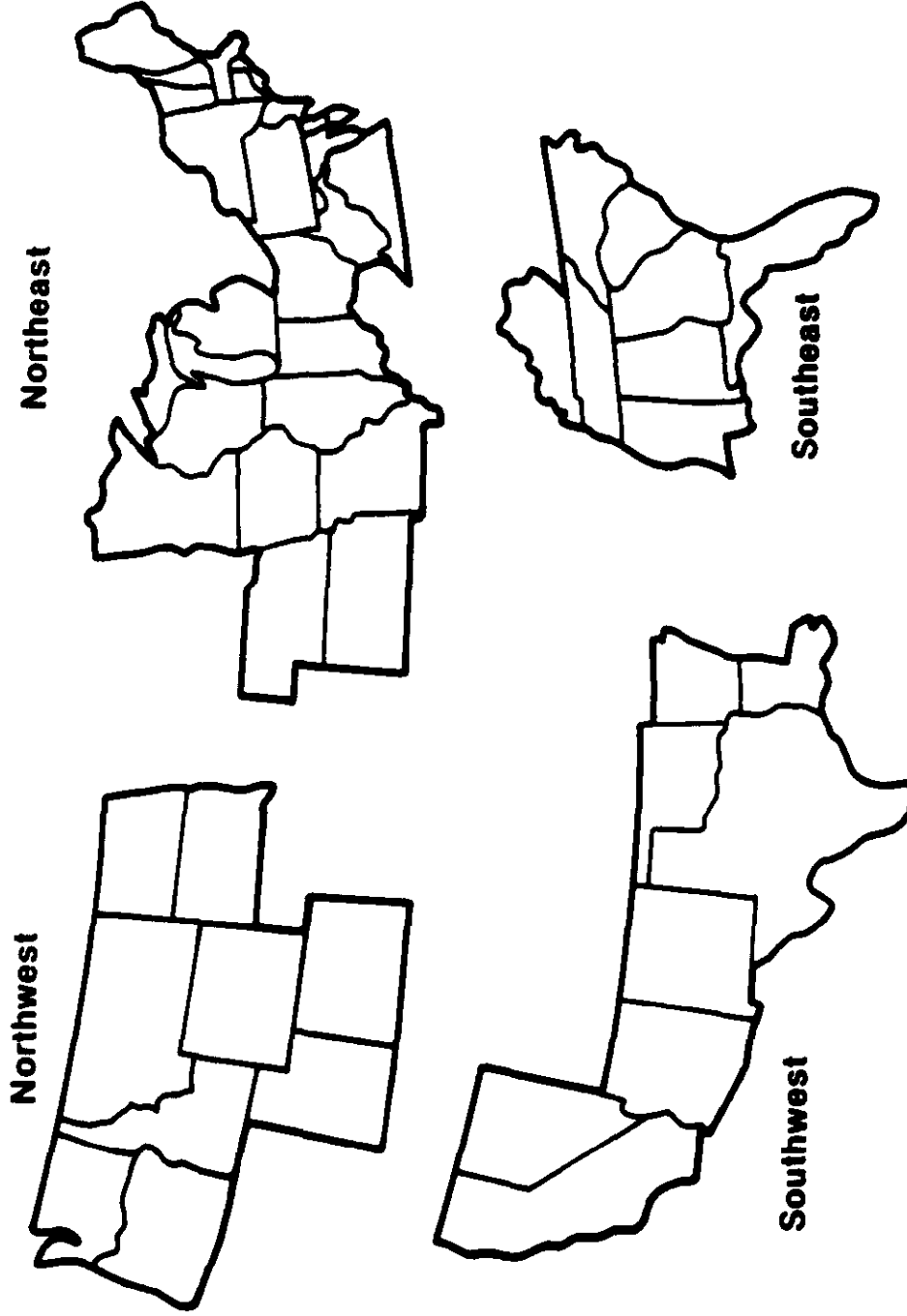


FIGURE 3. QUADRANTS FOR THE CONTIGUOUS UNITED STATES.

5.2 Identification of Respective Roles and Responsibilities

DOE

The DOE shall be responsible for monitoring all aspects of the project and for granting or denying all approvals required by the Cooperative Agreement. The DOE Contracting Officer is DOE's authorized representative for all matters related to the Cooperative Agreement.

The DOE Contracting Officer will appoint a Contracting Officer's Technical Representative (COTR) who is the authorized representative for all technical matters and has the authority to issue "Technical Advice" which may:

- o Suggest redirection of the Cooperative Agreement effort, recommend a shifting of work emphasis between work areas or tasks, and suggest pursuit of certain lines of inquiry which assist in accomplishing the Statement of Work.
- o Approve those reports, plans, and items of technical information required to be delivered by the Participant to DOE under the Cooperative Agreement.

The DOE COTR does not have the authority to issue any technical advice which:

- o Constitutes an assignment of additional work outside the Statement of Work.
- o In any manner causes an increase or decrease in the total estimated cost or the time required for performance of the Cooperative Agreement.
- o Changes any of the terms, conditions, or specifications of the Cooperative Agreement.
- o Interferes with the Participant's right to perform the terms and conditions of the Cooperative Agreement.

All technical advice shall be issued in writing by the DOE COTR.

Participant

The project will be the responsibility of MK-Ferguson's Cleveland operation. They will also establish a project office at the site where key personnel will provide centralized management and control of all project field activities.

MK-Ferguson's Program Manager will have total responsibility for design, engineering, procurement, construction, start-up, and operational testing of the facilities. He will be fully responsible for the execution of the overall program including the post-testing conceptual evaluations. The Program Manager will report directly to the MK-Ferguson Executive Vice President, Operations, and will perform the following:

- o Act on MK-Ferguson's behalf with power of attorney in all matters pertaining to the contract.
- o Provide total project management and direction, including development of policies, plans, procedures, schedules, and costs for the successful completion of the project.
- o Act as official point of contact for the Department of Energy, and as the authority for resolution of all contract matters.
- o Provide direction for completion of contract activities within the approved schedule, applicable codes, standards, plans, and specifications.
- o Enforce adherence to the policies and procedures approved by DOE.
- o Provide for complete integration of project support, technology, engineering, and site operations.
- o Provide the interface with Ohio Edison, including the Niles Plant Superintendent.

The Technology Manager will report to the Program Manager and have primary responsibility for implementation of the technical requirements of the project. He will lead the technical program definition and planning efforts, provide design criteria, conceptual design data, and other information required for the

design of the demonstration facility. He will supervise the shakedown and start-up of the facility and the performance testing program, including data collection and analysis.

In addition, the Program Manager will be assisted by the Project Controls Manager, the Construction Manager, the Engineering Manager and the Administration Manager. All of these individuals will report directly to the Program Manager.

The Project Controls Manager has primary responsibility for the implementation of an effective project Management Control System.

The Construction manager will be responsible for control of all project construction operations including both subcontractors and direct hire craft.

The Engineering Manager will be responsible for design engineering and procurement of all equipment purchased from the Cleveland office. He is responsible to the Program Manager and will work closely with the Program Manager in order to insure coordination between the design, engineering, procurement, and construction phases of the project.

The Administration Manager is responsible for the business and administrative functions of the project during both the design/construct and testing/analyses stages of the project.

Members of the project team will interface as shown in Figure 4.

5.3 Summary of Project Implementation and Control Procedures

All work to be performed under the Cooperative Agreement is divided into three phases. These phases are:

- o Phase I: Project Definition and Design (24 months)
- o Phase II: Construction (17 months)
- o Phase III: Operation (29 months)

As shown in Figure 5, there will be no gaps or overlaps between Phases.

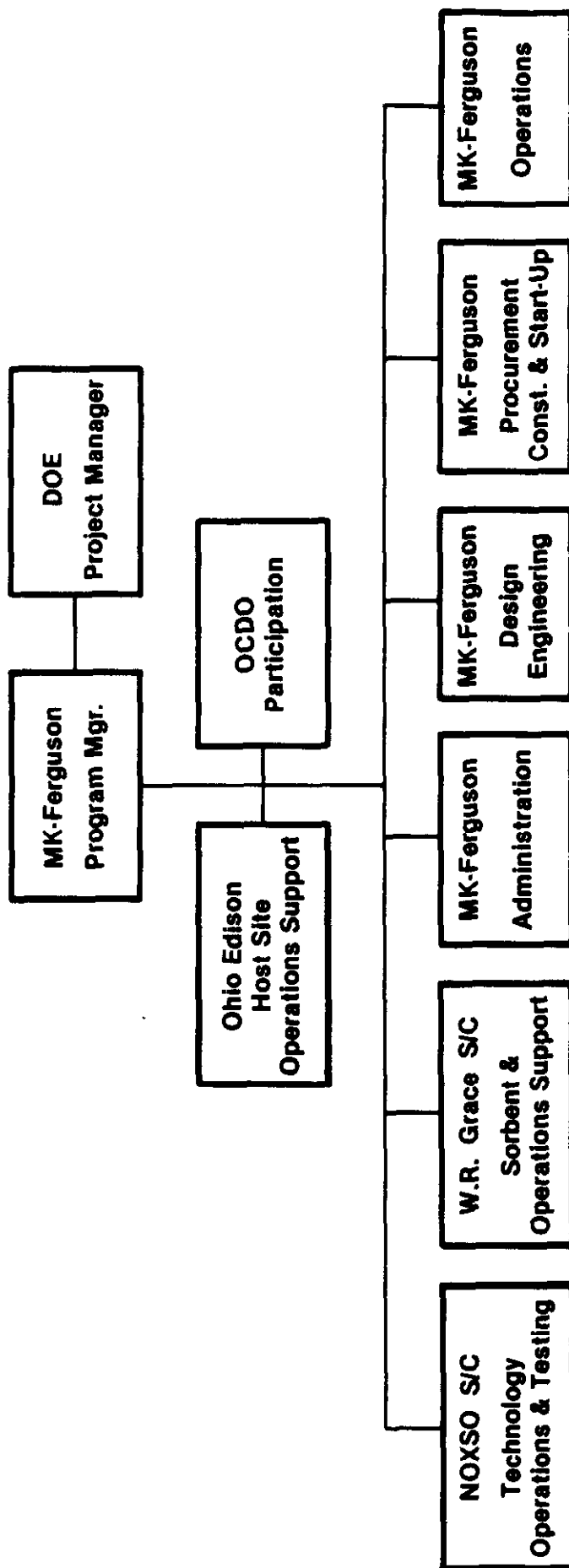


FIGURE 4. NOXSO DEMONSTRATION PROJECT ORGANIZATION.

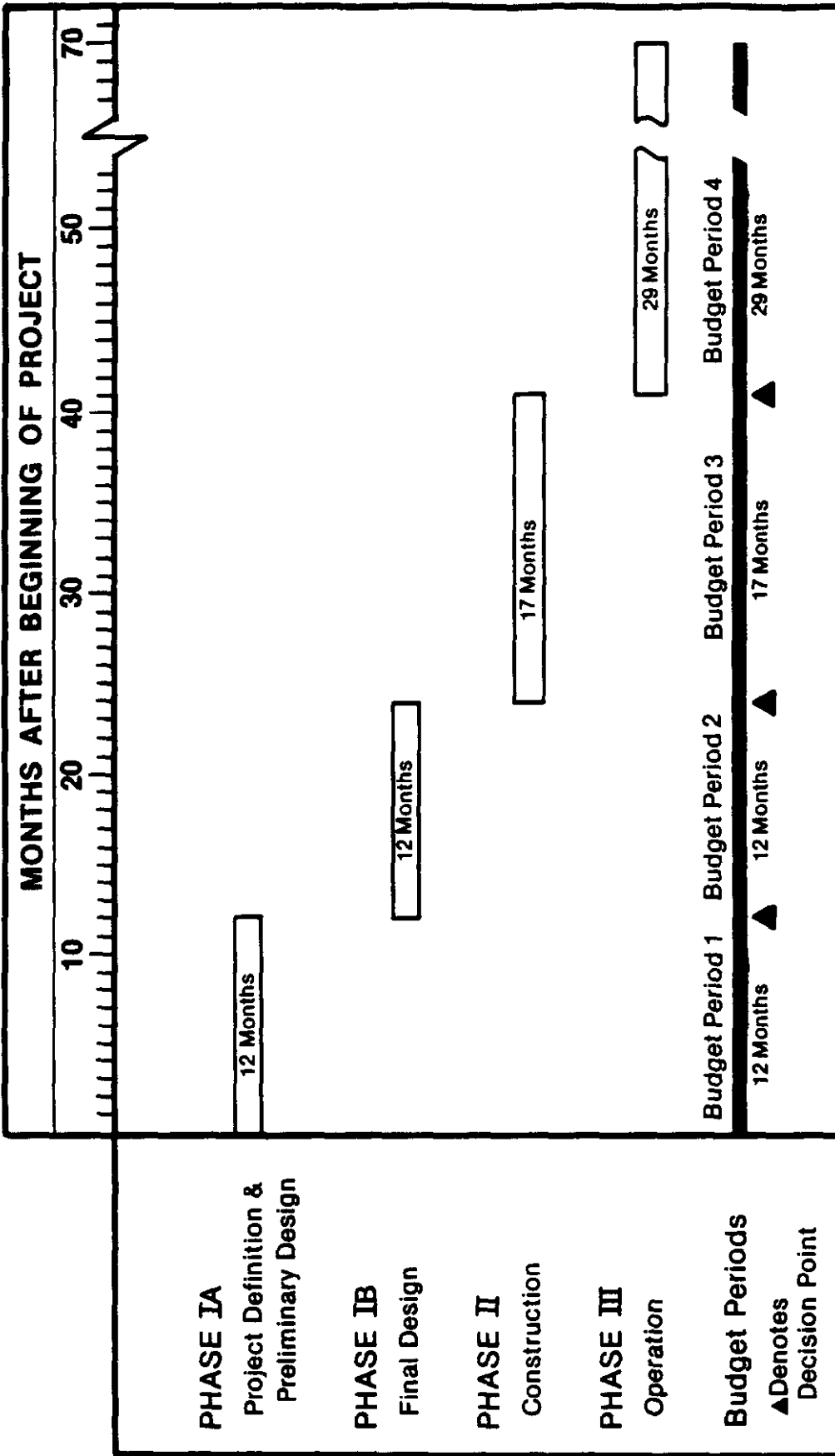


FIGURE 5. OVERALL NOXSO DEMONSTRATION PROJECT SCHEDULE.

Budget periods will be established to coincide with the project phases. Consistent with P.L. 100-446, DOE will obligate funds sufficient to cover its share of the cost of each budget period. Throughout the course of this project, reports dealing with the technical, management, cost, and environmental monitoring aspects of the project will be prepared by MK-Ferguson and will be provided to DOE.

5.4 Key Agreements Impacting Data Rights, Patent Waivers, and Information Reporting

MK-Ferguson's, NOXSO Corporation's, and W.R. Grace & Co. - CONN's incentive to develop this process is to realize business from the sale, lease or licensing of the NOXSO process to the utility and power boiler industry with respect to SO₂ abatement technology.

The key agreements in respect to patents and data are:

- o Standard data provisions are included, giving the Government the right to have delivered, and use, with unlimited rights, all technical data first produced in the performance of the Agreement.
- o Proprietary data, with certain exclusions, may be required to be delivered to the Government. The Government has obtained rights to proprietary data and non-proprietary data sufficient to allow the Government to complete the project if the Participant withdraws.
- o A patent waiver may be granted by DOE giving MK-Ferguson, NOXSO Corporation, and W.R. Grace ownership of foreground inventions, subject to the march-in rights and U.S. preference found in P.L. 96-517.
- o Rights in background patents and background data of MK-Ferguson and NOXSO Corporation and all of their subcontractors are included to facilitate commercialization of the technology.

MK-Ferguson will make such data, as is applicable and non-proprietary, available to the U.S. DOE, U.S. EPA, other interested agencies, and the public.

5.5 Procedures for Commercialization of Technology

The NOXSO team intends to market, engineer and construct the system and supply sorbent for the NOXSO flue gas emission control process. The process will be marketed worldwide to both utility and industrial coal-fired boiler operators. The completion of the demonstration project is the last step in the commercialization program.

The legislation amending the Clean Air Act will create a large potential for the NOXSO process. This market will primarily consist of two segments, existing coal-fired power plants and new coal-fired power plants. The NOXSO process will be applied to both market segments. The retrofit market will be the initial market for the NOXSO process. MK-Ferguson's main office is in Cleveland and is centrally located to plants located in the midwest which are most likely to be candidates for the utility market.

The features of the process that will make it attractive to the utilities are:

- o High SO₂ and NO_x removal efficiencies
- o Regenerable process
- o Sorbent is non-hazardous, composed of same compounds in fly ash
- o No chemicals introduced into flue gas
- o The process is dry, no sludge created
- o No waste streams, produces only sulfur which marketable
- o The process works downstream of the boiler air pre-heater

While this retrofit market will be the initial market for the NOXSO process, the Participant believes that as new coal plants are constructed in the mid-nineties and beyond, the NOXSO process will be a prime contender for the flue gas treatment system for the same reasons that make it attractive for the retrofit market.

6.0 PROJECT COST AND EVENT SCHEDULING

6.1 Project Baseline Costs

The total estimated cost for this project is \$66,249,696. The Participant's cash contribution and the Government share in the costs of this project are as follows:

	Dollar Share (\$)	Percent Share (%)
<u>PHASE IA</u>		
Government	3,000,000	50.0
Participants	3,000,000	50.0
<u>PHASE IB</u>		
Government	1,639,435	50.0
Participants	1,639,436	50.0
<u>PHASE II</u>		
Government	16,897,084	50.0
Participants	16,897,085	50.0
<u>PHASE III</u>		
Government	11,588,328	50.0
Participants	11,588,328	50.0
<u>TOTAL PROJECT</u>		
Government	33,124,847	50.0
Participants	33,124,849	50.0
	<hr/> 66,249,696	

Contributions will be made by the co-funders as follows:

DOE:	\$33,124,848
MK-Ferguson, NOXSO Corporation, and WR Grace & Company-CONN:	\$22,806,498
Ohio Coal Development Office:	\$ 5,000,000
Ohio Edison:	\$ 3,168,350
Gas Research Institute:	\$ 1,500,000
EPRI:	\$ 500,000
East Ohio Gas:	\$ 150,000

At the beginning of each budget period, DOE will obligate funds sufficient to pay its share of the expenses for that phase.

6.2 Milestone Schedule

The overall project will be completed in 70 months after award of the Cooperative Agreement.

Phase I, which includes project definition, host site characterization and preliminary design will last for 24 months. Phase II will start at the completion of Phase I. Phase II, which includes construction, will last for 17 months. Phase III will start at the end of Phase II and has an overall duration of 29 months. There is no overlap month between Phases II and III.

6.3 Recoupment Plan

Based on DOE's recoupment policy as stated in Section 7.4 of the PON, DOE is to recover an amount up to the Government's contribution to the project. The Participant has agreed to repay the Government in accordance with a negotiated Repayment Agreement to be executed at the time of award of the Cooperative Agreement.